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Round Table

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THE SUN

Its Effects on the Earth

An NBC Radio Discussion by LEO GOLDBERG
GERARD P. KUIPER, JOHN A. SIMPSON
and BENGT STRÖMGREN

Including

Solar Research at the McMath-Hulbert Observatory

By ROBERT R. McMATH and HELEN W. DODSON

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SOLAR RESEARCH AT THE McMATH-HULBERT OBSERVATORY
By ROBERT R. MCMATH *and* HELEN W. DODSON 11

THE UNIVERSITY OF CHICAGO ROUND TABLE
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The Sun: Its Effects on the Earth

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MR. KUIPER: Great progress has been made in the last few years in the understanding of solar phenomena. This has come as the result of new techniques, like better gratings, the introduction of interference filters, the development of solar radio astronomy, and in the progress of atomic and nuclear physics as applied to solar physics. Therefore, it is appropriate to review at this time the subject of the sun and its effects on the earth.

In particular we want to review a few questions which are of interest to the general audience. For instance, are the ice ages which have appeared on the earth the result of changes in sunlight? That is, is it possible that the ice ages were the result of changes in the energy output of the sun? What is the effect of the sun on the weather? What is the age of the sun? When will the sun die and life on the earth with it?

Here today on this ROUND TABLE we have a panel of experts on the sun and its radiations.

Goldberg, you have studied the composition of the sun. What can you tell us about it?

MR. GOLDBERG: I would like to say, first, that the advances in this field of solar physics have really been exciting and spectacular in the last few years. It is really quite an experience for a worker in this field to read the large volume on the sun which has just been published by the University of Chicago Press with something like twenty-three authors from six different countries.[1]

It seems to be very well established, to go back to your question, that the sun is composed of the familiar elements which we find here on earth but in rather different proportions. That is to say, the sun is made up mostly of hydrogen, a little helium, and about 1 per cent of the heavier elements like carbon, nitrogen, oxygen, iron, and so forth.

[1] Gerard P. Kuiper (ed.), *The Solar System*, Vol. I: *The Sun* (Chicago: University of Chicago Press, 1953).

MR. KUIPER: So the earth really is a very special bit of cosmic matter in that the light materials have mostly been lost and that predominately the heavy elements are left.

Simpson, you have given a great deal of attention to the study of cosmic rays. Can you tell us a bit about the radiations which are coming from the sun?

MR. SIMPSON: Most of the radiations known to exist in physics today are also found to be produced by the sun. For example, we now know that there are radio waves, infrared radiation, the visible light which we see every day, ultraviolet radiation at shorter wave length. Then, as we go even farther into the higher energies, we find X-rays; and then, at even greater energies, the aurora particles. At the extreme high energies, cosmic rays themselves are found.

MR. KUIPER: It might be of interest if we started this discussion with an exploration of the deep interior of the sun—the place where the sun produces all the energy which it emits. Strömgren, what is the temperature in the center of the sun?

MR. STRÖMGREN: The central temperature of the sun has been computed to be about 23,000,000 degrees Fahrenheit. This compares with a surface temperature of about 9,000 degrees.

MR. KUIPER: If the sun has such a mixture of gas which, as Goldberg has just said, is mostly composed of hydrogen and some helium, and about 1 per cent of the heavier elements, and at a temperature, as you say, of about 23,000,000 degrees Fahrenheit, what sort of physical processes would you say occur in such a place?

MR. STRÖMGREN: As a consequence of the high temperature, the atomic particles in the solar interior move about with great speeds. They therefore collide with each other much more violently than the atoms on the earth. This means that the atomic nuclei react with each other much as they do in the hydrogen bomb. The most important of these nuclear reactions start with a collision between two hydrogen nuclei—protons, as they are called—and the net result of the nuclear processes is the conversion of hydrogen nuclei into helium nuclei.

MR. KUIPER: Would you say that the amount of energy which is liberated in this process is large compared to the familiar chemical processes, like the burning of coal?

MR. STRÖMGREN: The conversion of hydrogen into helium in the cen-

tral regions of the sun is accompanied by an enormous release of energy. From the point of view of the physicist, the burning of coal is a minor readjustment of the outer electrons; whereas, through the nuclear process, a major transformation of matter takes place that releases these great energies.

MR. GOLDBERG: Would you say, then, that the basic fuel which keeps the sun burning or shining is hydrogen and that this fuel is used up and converted into helium?

MR. STRÖMGREN: Yes, that definitely seems to be the case.

MR. KUIPER: Then, as the result of this conversion of hydrogen to helium, the sun must be aging. What is known about the age of the sun and the duration during which the sun will continue to produce its energy?

MR. STRÖMGREN: The age of the sun is about four to five billion years. This result has been derived from study of the decay of radioactive elements. We know the energy radiated by the sun per second; and we can thus compute the rate at which the available hydrogen fuel is being used up. It has been found that the available hydrogen fuel supply will last for a total time of about ten billion years.

MR. KUIPER: You say that the sun started out about five billion years ago and that the total life is going to be about ten billion. So, I take it, the sun is about halfway in its career.

MR. STRÖMGREN: Yes, that is the conclusion which is reached.

MR. KUIPER: I think that we should explore one consequence of our understanding of the production of solar energy—namely, what effect it must have on the energy output of the sun. Would it be possible for the sun to change its brightness very appreciably within comparatively short spans of time?

MR. STRÖMGREN: This does not seem to be the case. The sun has an enormous store of energy, and this would smooth out variations.

MR. SIMPSON: In other words, you would say that, in the short lifetime of man on the earth, and, in fact, the lifetime of the earth itself, many of the variations of temperature seen on earth cannot be attributed to changes in solar radiation?

MR. STRÖMGREN: According to our present picture of the solar interior, it is definitely the case that it could not be.

MR. KUIPER: The most important of the changes which we have seen in the temperature of the earth are the ice ages. If one goes back over the last five hundred million years or so, one finds definite evidence from the fossils that the temperature on the earth has changed very appreciably. There have been times when the temperature was around the freezing point—that is, the average temperature of the whole earth was around the freezing point. At present it is around 60 degrees Fahrenheit. But during large intervals the average temperature was appreciably higher than it is now.

We have then the very important question of whether these large changes can be attributed to changes in the sun. Strömgren, what would you say about that?

MR. STRÖMGREN: One perhaps might imagine that the energy production might vary. It is the sensitive function of the central temperature. Let us suppose, for instance, that the central temperature went up a little. One might imagine that the energy production might become greater. However, as we understand the conditions, we have reached the conclusion that the mechanism is self-regulating. Any little increase in temperature would lead to an expansion of the sun with a consequent decrease in temperature; and the radiation would remain very much the same all the time.

MR. KUIPER: That is, an increase of production would cause an increase of temperature; the increase of internal temperature would cause an increase of size and expansion . . .

MR. STRÖMGREN: Yes.

MR. KUIPER: . . . which would automatically decrease the production again.

MR. STRÖMGREN: And that would bring down the temperature. So the mechanism is self-regulating and keeps the energy radiation at very much the same value.

MR. KUIPER: Is it not true also that there is another factor which is important here? That is, the heat content is enough for the radiation of about a million years; and, therefore, any instantaneous increase in production would not be able to do very much anyway.

MR. STRÖMGREN: This regulating mechanism in itself would smooth out short-term variations certainly.

MR. KUIPER: So that the two effects combined—the intrinsic stability and the large heat content—would smooth out the energy output.

MR. GOLDBERG: When you speak of the heat content, what you really mean is that, if the source of the solar energy were suddenly shut off, the sun would go on shining for about a million years?

MR. KUIPER: That is correct. That was what I meant by referring to the heat content. There is a big reservoir which would continue to supply radiation, even if the production were cut off. It is a very comfortable feeling to know that the sun has still about five billion years to go and that, if we manage properly on the earth, life on the earth will also probably have another five billion years to go.

One interesting question about the ice caps during the ice ages is that, once a large ice cap forms, it tends to persist as a result of the fact that the large ice cap reflects the solar radiation falling on it—rejects the heating-up process by the sun; and the ice cap radiates to outer space very effectively. One can well understand that certain current systems on the earth itself are responsible for the ice ages. That is, a change in the circulation is responsible rather than a change in the sun.

So much then for the long-range changes. We are interested also in the short-term effects of the sun on the earth.

Goldberg, would you tell us something about sunspots?

MR. GOLDBERG: The sunspot is frequently a very conspicuous feature on the surface of the sun. When you look at the sun through an ordinary telescope, using a dark glass, of course, to protect your eyes, you are apt to see small dark areas which have been called sunspots. These areas are only relatively dark. Their temperature is 3,000 or 4,000 degrees below that of the surrounding surface, and so they look dark by contrast.

MR. SIMPSON: Would you say that our first indications that the sun rotates were derived from observing these sunspots over extended periods of time?

MR. GOLDBERG: Yes, the rotation was first noticed by Galileo, as a matter of fact. The spots appear from day to day to move from east to west across the face of the sun. This is a consequence of the fact that the sun rotates once in twenty-seven days.

MR. STRÖMGREN: We spoke earlier in terms of millions and billions of years. How long does a sunspot last?

MR. GOLDBERG: Usually from a few days to a few weeks; sometimes as long as even a few months. I might point out also that one of the most interesting features of sunspots is that they have very strong magnetic fields associated with them.

MR. KUIPER: How do the field strengths compare to what we are familiar with on the earth? There is on the earth our own magnetic field, which directs the needle of the compass. How much stronger are the fields in sunspots?

MR. GOLDBERG: Oh, I would say sometimes two to three thousand times as strong on the sun. They are enormous fields.

MR. SIMPSON: In addition to the sunspots, Goldberg, I believe that your group has been investigating transient phenomena which are quite dramatic on the sun, such as flare effects and other associated phenomena. What can you say about them?

MR. GOLDBERG: Yes, indeed, in regions where the sunspots occur there is likely to be very spectacular activity. One can see clouds of gas being ejected from the sun at very high speeds, up to five hundred or even a thousand miles per second. Local regions appear to brighten very suddenly. We call these "flares" for rather obvious reasons; and this solar activity seems to have very profound effects on the earth.

MR. KUIPER: All this turmoil in the solar atmosphere does not affect the temperature on the surface of the earth, does it?

MR. GOLDBERG: No, not at all. It has its greatest effect on the upper atmosphere of the earth.

MR. SIMPSON: This upper atmosphere to which you are referring, I judge, is the invisible region called the ionosphere, which can affect the radio waves which we use in communications.

MR. GOLDBERG: Yes. Very high up in the earth's atmosphere, perhaps thirty to one hundred and fifty miles up, one finds about five electrified layers. These layers are electrified because ultraviolet radiation from the sun bombards the atoms and molecules and tears loose electrons so they become charged. These layers then act as reflecting mirrors to return radio waves from the earth; and in this way long-distance radio communication is possible, because otherwise the waves would go out into space.

MR. KUIPER: At this point we might well remind our audience that on June 30 there will be a total eclipse of the sun, which will be visible

in the northern part of the United States—northern Wisconsin and northern Michigan—Canada, and Europe, at 6:10 A.M., Chicago time. That is on June 30. This will give an opportunity to see outer layers of the sun, the chromosphere and the corona, which normally are not visible to the eye.

We should say a few words here about the magnetic storms and the aurorae. Goldberg, what is the accepted explanation for the aurorae?

MR. GOLDBERG: Apparently during the time of very great sunspot activity, and especially in connection with flares, clouds of charged particles are emitted from the sun, also ultraviolet radiation. These clouds of particles can and do strike the earth's atmosphere and are apparently responsible for the aurorae and magnetic storms.

MR. SIMPSON: We should say that, if you were to look at the sun today, however, you might not see some of these phenomena we were just talking about now.

MR. GOLDBERG: Yes, that is very true. The number of spots which can be seen on the sun at any one time is quite variable. They vary in roughly an eleven-year cycle. We happen right now to be down near the bottom of the cycle; we have just started up, as a matter of fact. In four or five years the sun will be very spotted, indeed.

MR. SIMPSON: So, if the radio listener were to go out after hearing this broadcast and look at the sun, he is liable not to see any spots whatsoever, I imagine, at this time.

MR. GOLDBERG: There is a very good chance that there will be no spots at all today.

MR. KUIPER: We might well discuss in a little more detail the particles which the sun emits. In particular we are interested in the extremely fast and penetrating particles which are called cosmic rays and to which Simpson at the Institute for Nuclear Studies has given a great deal of attention. How do you go about, Simpson, observing those particles, the cosmic rays?

MR. SIMPSON: Cosmic radiation reaches the earth from all directions at all times, and it is composed of the nuclei of the elements which we find in our universe. The protons are nuclei of hydrogen and constitute most of the particles. These charged particles arrive at very high energies. If they come from the sun, they would arrive at the earth within approximately fifteen minutes.

MR. KUIPER: Do you make all your observations here at Chicago? Or do you have a number of stations and collaborating observatories in various lands?

MR. SIMPSON: I shall come back to that question in a moment after I mention something about "cosmic radiations." These particles of very high energy, which incidentally are about a million to a billion times more energetic than the radiations about which we have been talking heretofore, have a small contribution from the sun. The sun is able to produce a minor portion of this radiation; and superimposed on the general cosmic radiation background is also the intensity variation which one can relate to the rotation of the sun itself. Thus, it is clear that some cosmic-ray phenomena are associated with the sun; and we are interested in making observations on these variations.

MR. KUIPER: Now I understand, then, that the sun does not always necessarily emit cosmic rays but that there are certain times when the sun sends out a burst of cosmic rays. I believe that those are associated with the flares. Is that not right?

MR. SIMPSON: That is correct. And since we wish to study how these particles obtain their energies, we must have some way to sort out these incoming particles according to energy. Now, to do this, we use the earth's magnetic field itself as a giant energy spectrometer for the incoming radiation. The magnetic field at the Equator will cut off all except the highest energy particles; and at the Pole, the magnetic field being very weak, will admit particles of even the lowest energies. So, by having a series of stations and aircraft extending all the way from the Equator to the Pole we are able to analyze the energies.

MR. GOLDBERG: Then you do work closely in collaboration with the people who observe the flares?

MR. SIMPSON: I think that that is essential, because, if the mechanism which is producing these particles is, indeed, the flare, we want to understand something about the visible effect, the visible region of the flare, as well as these very high-energy acceleration mechanisms.

MR. KUIPER: I think that the audience would be interested in a few details about your stations and about your flights.

MR. SIMPSON: At the University of Chicago we have arranged to have a series of laboratories. One of them is in the Andes, in Peru, one in Mexico City, one in New Mexico, one in the mountains of

Colorado, and one at sea level in Chicago. The aircraft which we have been using are able to run the course from Fairbanks, Alaska, to Lima, Peru, or from New Orleans to Churchill; and observations are made on a continuous basis at the stations and on an intermittent basis with the aircraft.

MR. KUIPER: How long has this program been going on?

MR. SIMPSON: About four years. And we are learning much which will eventually relate the mysterious solar magnetic fields to the cosmic radiation changes which we now observe.

MR. KUIPER: It is of great interest really to reflect on the enormous range of particles which the sun is sending to us. These extremely fast cosmic rays are really not fully understood in detail, where they come from—that is, how the sun is able to produce them. We understand a little more about the particles which cause the aurorae, because they are much slower.

MR. GOLDBERG: I wonder if Mr. Simpson could say something about possible mechanisms by which charged particles—like cosmic rays—can be shot out from the surface of the sun? This is not obvious.

MR. SIMPSON: It certainly is not. In fact, we do not know the process. We can guess that the process is related to the kind of accelerators which we are now designing on earth. We are not sure that it is. We know that in the regions from which the cosmic rays come there is radio emission, there is the visible light which you observed, Goldberg, and there are sometimes even the auroral particles.

MR. KUIPER: In any case I think that our great hope is to find out a great deal more about this from the recent advances which have been made by the Babcocks at the Mount Wilson Observatory in California. In studying the details of the magnetic field of the sun on a day-to-day basis, they have developed extraordinarily sensitive equipment and trace on every clear day what they call a "magnetogram," a record of the distribution of the magnetic field over the sun. And it is quite clear that the changes of the magnetic fields in certain areas on the sun, from day to day and from hour to hour, will eventually give a clue to the way in which the sun is able to produce those very fast particles.

MR. SIMPSON: I might say the cosmic-ray physicist looks with interest on the Babcocks' measurements, because they are directly comparable to the measurements being made in cosmic-ray physics. We should eventually meet somewhere in one of the adjoining fields.

MR. KUIPER: I believe that we have a very good example here of the new technique developed in the last two or three years, which is yielding very important information and which simply was not available three or four years ago.

We want to say, finally, a few things about the effect of the sun on the weather.

MR. STRÖMGREN: When we realize, on the one hand, that the energy output of the sun is very stable and, on the other hand, compare this with the turmoil which we find in the outer layers, I think that we wonder what their effect on the earth would be. In this connection it seems to be quite important to realize that the layers which we observe directly, and which are in a turmoil, constitute only a very small fraction of the total mass of the sun, about one-tenth of a billionth of the total mass. So that, on the whole, one would say that the sun is a very steady source of energy. Superimposed on the flow of energy there is certain turmoil which will cause disturbances.

MR. KUIPER: Is it not true that the turmoil which exists in the outermost fringe of the sun, which is so very unimportant on the basis of the mass, affects in turn only the outermost fringe of the earth, which is also terribly unimportant in terms of mass—the outer fringes of the sun affecting the outer fringes of the earth.

MR. STRÖMGREN: Yes, indeed. If you think of it in terms of energy transported from the sun to the earth and the effects on the earth as a whole, then we arrive at this picture of a very steady state.

MR. KUIPER: So, in no case do we have an explanation here of the day-to-day weather which we have on the earth.

MR. SIMPSON: On the other hand, this very small amount of energy which is coming in from the turmoil region has an exceedingly important effect on the earth.

MR. KUIPER: We have concluded, I believe, that the average temperature on the earth does not change because of changes in the sun. The earth's ice ages must be explained by forces and currents operating on the earth itself. We know that the violent short-term charges on the sun affect only the uppermost atmosphere of the earth—the ionosphere—and, as a result, we have radio transmission and fadeouts, but they have no effects on the weather.

SOLAR RESEARCH AT THE McMATH-HULBERT OBSERVATORY*

By ROBERT R. McMATH *and* HELEN W. DODSON

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Of all the astronomical bodies that now impinge upon the serious consideration of twentieth-century man, the sun is at the forefront. This pre-eminence of the sun in current interest stems not so much from a realization of our complete dependence upon it for light, heat, and power, but more from a recognition of the fact that the sun undergoes changes from day to day, even hour to hour, and that some of these changes on the sun affect the practical affairs of man. Solar research is no longer the milieu of just the "starry-eyed." Nowadays the radio engineer, the telephone company, the cosmic-ray specialist, the nuclear physicist, the Army, the Navy, and the Air Force, for one reason or another, have a concern with what is happening on the sun.

In a certain sense the sun has long been of interest to scientists outside the circle of professional astronomers. The sun is recognized as a laboratory with physical conditions impossible to duplicate in terrestrial establishments. Solar temperatures, pressures, and densities permit processes to occur that cannot be expected to take place in terrestrial laboratories. Atoms of iron, nickel, and calcium in the corona, the great outer atmosphere of the sun, radiate freely certain frequencies that are labeled "forbidden" in terrestrial textbooks. Element No. 2 in the periodic table of the elements bears constant witness to the fact that solar physics, from its very inception in the middle of the nineteenth century, has played a part in the progress of the physical sciences. The element helium was indeed discovered in the sun decades before it was found to exist on the earth.

The new interest in the sun, however, does not result from an appreciation of its value as an extra-terrestrial laboratory—great though this is. In its new role, the sun and the earth together form a sort of

* Adapted from Robert R. McMath, "Solar Research at the McMath-Hulbert Observatory," *Publications of the Astronomical Society of the Pacific,* LXIV (1952), 151 (the Robert Grant Aitken Lecture given at the joint meeting of the A.A.S. and A.S.P. in Victoria, B.C., June 25, 1952), and Helen W. Dodson, "The Sun: The Earth's Near and Disturbing Neighbor," *Michigan Alumnus Quarterly Review,* LIX (1952), 62. (Reprinted by special permission.)

cosmic "apparatus." The sun is the scene of rapidly changing physical processes, and the entire earth, some 93,000,000 miles away, reacts. The earth plays the part of the photographic plate or electronic recorder in the more conventional laboratory equipment. The earth's ionosphere, that electrically charged region of the upper atmosphere, acts as a detector to indicate that changes have taken place on the sun. The earth as a whole intercepts about one part in two billion of the total solar radiation. Small as this is, it is enough to result in significant changes in the earth's ionosphere when there are variations in the amount of ultraviolet light radiated by the sun.

It so happens that many of the affairs of the current period in history are dependent on the stability of the earth's ionosphere. Communication by radio, telephone, and telegraph can all be upset if the earth's ionosphere or the terrestrial magnetic field are greatly disturbed. The new widespread interest in solar research emanates in large part from the importance of maintaining long-distance communication in the global cultures and responsibilities now evolving on the earth. Although this interest centers in the field of investigation known as solar-terrestrial relationships, it includes a broad support of fundamental solar research. Even though the sun is the nearest star, a star so close that we can watch changes on its surface, solar astronomers still do not clearly understand the changes that take place. It is hoped that, by progress in the study of the sun itself, the solar events that cause terrestrial effects may in time be recognized and the periods of terrestrial disturbance predicted.

Throughout the world there are relatively few astronomical observatories in which solar research constitutes the primary program. The McMath-Hulbert Observatory of the University of Michigan is one of this small number of institutions dedicated entirely to problems of solar physics and solar-terrestrial relationships. This observatory, developed during the last twenty years, has laid great stress on the use of instruments designed especially to fit particular observational problems. Furthermore, the instruments are modified or changed as the emphasis in the research program changes and as new techniques become available. Instrumentally, solar physics is a highly dynamic science. At the present time two great solar towers and a photometric telescope provide data for extensive and integrated studies of the physics of the sun. Auxiliary spectrographs, spectrometers, and electronic detectors permit specialized analyses of the basic solar radiation. With

some of these instruments monochromatic pictures of the sun are recorded in the light radiated by hydrogen and calcium atoms. Some of these studies show the rapid and puzzling motions of the prominences, vast clouds of glowing gas that extend high above the solar surface. The original 50-foot tower telescope and associated spectroheliograph were designed primarily for high-resolution photography of solar prominences. As the study of prominence motions developed, it became apparent that information about line-of-sight motions of the prominences was an integral part of a thoroughgoing attack on the problem. To meet this need, a second solar telescope and a spectroheliograph for recording the Doppler shift of the solar gases were installed within the original 50-foot tower.

It is not enough to know what is happening on the sun. It is important to try to understand why the changes take place. With this goal in mind special instruments have been designed to permit the simultaneous study of selected solar features with a battery of instruments. For example, while the changes in height and velocity of a prominence are being recorded in the 50-foot tower, the details of the spectrum of selected parts of the prominence can be recorded with a choice of instruments in the 70-foot tower (McGregor Tower).

The original instrumentation of the McGregor Tower included a 25-foot Littrow-type spectrograph designed for the photography of spectra of solar phenomena and for the two-dimensional scanning of small areas in monochromatic radiation. After World War II, when the development of the lead sulfide cell had opened the way to high-resolution exploration of the infrared spectrum, a new all-reflecting telescope and spectrograph were designed to take advantage of this significant technical advance.

Even more recently very great advances in the grating art have been made through the design of the so-called "*échelle* grating" by G. R. Harrison and through the new rulings made by the Babcocks in Pasadena. The *échelle* grating makes possible great wave-length coverage with high dispersion on a relatively small photographic plate. The Babcock gratings are designed to provide maximum efficiency and high resolution in chosen wave-length regions. Provision has been made in the original spectrograph of the McGregor Tower for use of an *échelle* grating. At the present time a large vacuum spectrograph is under construction to permit realization of the high resolving power of the new Babcock grating under practical observing conditions. Ex-

periments have proved that bad seeing inside the spectrograph materially affects the quality of the results when resolving powers of the order of half a million are sought. Improvements and changes in instrumentation are undertaken in the hope that more precise observational material will thus become available and in turn permit more clear-cut determinations of the physical conditions on the solar surface and in its outer atmosphere.

Records of the solar spectrum constitute the most basic of solar observations. In recent years an important part of the observing time of the McMath-Hulbert Observatory has been given to the mapping of the infrared solar spectrum. New photoconductive cells permitted increased accuracy both in wave-length and in energy measures. A part of the mapping program has already been published in *The Infrared Atlas,* with wave lengths from 8400 to 25,000 angstroms. The wave-length limit on the short side was chosen so that the *Infrared Atlas* and the *Utrecht Atlas* of the photographic and visual regions would overlap by about 300 angstroms. The long wave-length limit was set by water-vapor absorption in the earth's atmosphere and by the lack of response of an uncooled lead sulfide photoconductive cell to radiation of longer wave lengths. A cooled lead sulfide cell has been used to continue the mapping of the solar spectrum to a long wave-length limit of 36,000 angstroms, but with reduced resolving power. The mapping has been further continued to 50,000 angstroms through the use of a lead telluride photoconductive cell, cooled with liquid oxygen. The excellent cells used in this work were made by Dr. R. J. Cashman.

The mapping of the solar spectrum is concerned with the identification of the origin of spectrum lines as well as with their wave lengths and energies. It is desirable to know not only the kind of atom that produces the spectrum line, but whether the atom is located in the atmosphere of the sun or of the earth. The identification of a spectrum line as solar or terrestrial in origin is a problem common to all wave-length regions. Many considerations permit the identification of solar lines. Earth lines strengthen as the sun approaches the horizon; solar lines do not. A solar line observed first at the east limb on the sun's equator and then at the west limb on the equator will shift its position with reference to terrestrial lines, because of the sun's rotation. Some solar lines show large changes in strength that become evident when one compares records made at the center of the disk with others made at the edge of the sun. Since water vapor is present in highly variable

amounts in the earth's atmosphere, comparison of records made on days of low water-vapor content with records made on days of high content helps to identify lines due to this source. All these effects have been used to separate solar from terrestrial lines. Also some solar lines show changes in the near infrared sunspot spectrum, but only a beginning has been made in this study. Of the approximately 7500 lines observed in the infrared spectrum of the sun, more than 800 are certainly of solar origin.

A program of observation of the sun at very low altitudes showed that most of the spectrum lines recorded were of terrestrial origin. This made observations from a higher altitude desirable, and, by arrangement with Dr. I. S. Bowen, an instrument like that at Lake Angelus was installed on Mount Wilson in the Snow Telescope spectrograph room. This installation, completed in May, 1949, is operated cooperatively by the McMath-Hulbert Observatory and the Mount Wilson and Palomar observatories, with financial assistance from the Office of Naval Research.

The study of the infrared solar spectrum has found immediate application. Dr. Leo Goldberg has used the wave-length measures to improve the molecular constants of terrestrial carbon dioxide, methane, and nitrous oxide. Dr. Goldberg has further shown that the observed change of strength of the methane lines can be satisfactorily predicted on the assumption that methane is well mixed with the permanent and abundant constituents of the earth's atmosphere. Furthermore, nitrous oxide, a compound that is very sensitive to the far ultraviolet radiation of the sun and which may be one of the atmospheric constituents responsible for the ionization of the earth's upper atmosphere, is apparently almost absent in the noonday solar spectrum at wave lengths short of 25,000 angstroms. However, it becomes easily visible in certain infrared wave lengths as the sun approaches the horizon.

Some of the solar lines show large changes in intensity between the center and edge of the sun. The λ 10,830 line of helium is outstanding in this respect. Lines of *CO*, present in the sun, were found strengthened at the edge of the sun.

Spectroheliograms, or monochromatic pictures of the sun, show in spectacular detail the motions and development of the transient solar features—prominences, "flares," as well as sunspots with their surrounding bright plages. These solar pictures are, in truth, nothing more than composite records of the variations in intensity of a chosen

spectrum line across the surface of the sun or a chosen solar feature. Through ordinary telescopes, where all colors or wave lengths are included in the image, flares and prominences are usually not visible. It is only when the observations or photographic plates are limited to the red light radiated by hydrogen atoms or to the violet light of ionized calcium that these special features are easily seen. When spectroheliograms are recorded at intervals of 10–30 seconds and then projected by the moving-picture technique, certain rapid changes on the sun are dramatically portrayed.

Beginning in 1936, the 50-foot tower of the McMath-Hulbert Observatory produced motion-picture films showing prominence motions. There were the great ascending prominences that rose hundreds of thousands of kilometers before the material fell back to the solar surface. Bright loops formed in the neighborhood of sunspots, and material moved down both branches of the loop from an apparently inexhaustible source at the top. Loops formed in the presence of an almost ceaseless rain of material falling toward the sunspot region beneath. These pictures challenged the imagination and defied the theoreticians.

The best hope for progress in understanding the prominences seemed to lie in a program in which emphasis was placed on the study of the more simple types of prominences rather than on the most complex, in which spectrum observations whenever possible supplemented the data on form and cross motions, and, finally, in a program in which the prominences were studied with respect to their total surroundings on the solar disk. Because of its apparent simplicity, the surge-type prominence was chosen for special study. The surge is a prominence which moves outward from the chromosphere and then falls back along the same path. Surges vary in size from tiny spikes to giants which reach heights of 100,000 km or more.

The study of surges has produced several interesting results. The first stems from the variation of the height of the surge with time. Plots of radial height versus time show close similarity to the changes of height with time calculated for bodies falling freely under solar gravitation. It must be emphasized, however, that the path followed by the surge is very different from that of a freely falling body.

A second outcome of the study of surges results from measurement of $H\alpha$ spectra secured with the Stone spectroheliograph, concurrently with the usual prominence pictures. These spectra record a change in

the direction of the line of sight velocities, *in phase* with the apparent rise and fall of the surge.

Similar $H\alpha$ spectra secured during the activity of the more complex eruptive prominences also show Doppler shifts which indicate the presence of moving material. The evidence of Doppler shifts in these prominences does not *deny* the possibility of traveling excitation, but it does *affirm* the presence of moving hydrogen atoms.

In order to study prominences with respect to other solar phenomena, it seemed wise to build up an extensive collection of prominence photographs taken without an occulting disk. Such $H\alpha$ spectroheliograms of limb and disk provide data for the determination of intensities of the prominences in terms of the undisturbed $H\alpha$ disk. Furthermore, the *development* of prominences is more clearly indicated when the disk as well as the limb can be studied.

It is through monochromatic studies of the disk itself that observations of particular interest in solar-terrestrial relations have been secured. At the present time there are two recognized groups of terrestrial effects that are thought to be associated directly with solar causes. The first is a series of sudden ionospheric disturbances on the earth that occur practically simultaneously with the observed outbreak of a bright "flare" on the sun. These ionospheric disturbances occur on only the sunlit hemisphere of the earth. Some of them last for tens of minutes and some for several hours. During such periods there are fadeouts on long-distance radio transmission channels for frequencies between 5 and 20 megacycles per second. These short-wave radio fadeouts are the most usually recorded terrestrial effects of a solar flare, but they are not the only ones. On certain very long radio wave lengths (11,500 meters) there is improved reception of distant "atmospherics"; on still other frequencies unusual phase anomalies occur. During certain flares the sensitive compass needles, recording the strength and direction of the earth's magnetic field, show characteristic tremblings.

When a solar astronomer observes the outbreak of a flare, he sees a small portion of the surface of the sun, usually near a dark sunspot, brighten three- to sixfold in the light radiated by hydrogen and calcium atoms. Flares are usually not visible unless the observations are made in the monochromatic radiation of hydrogen and calcium atoms. Some flares are small round regions; others are great ribbon-like formations hundreds of thousands of miles in extent. Since flares and

sunspots occur in the same parts of the sun, they probably represent two aspects of great solar storms or regions of excessive activity and changing forces.

The physical mechanism of the flare is not yet understood, but it is thought to include a sudden burst of intense ultraviolet radiation. All the terrestrial effects coincident with the outbreak of a flare can be explained by an increase in the ionization of the lower part of the earth's ionosphere, the D layer, as a result of a burst of intense ultraviolet light from the sun. On the surface of the earth, beneath the protective blanket of the upper atmosphere, we are shielded from these very short-wave radiations that burn living tissues. For our physical well-being this is a great advantage, but for the progress of solar research it is indeed a stumbling block. Because of this absorption by the earth's atmosphere, we cannot observe directly variations in far ultraviolet radiation that take place on the sun; we can only deduce that they have occurred from secondary effects produced on the sun or on the earth. Both the increase in the observed brightness of the red light radiated by hydrogen in the "flare" and the changes in the electrical properties of the D layer of the earth's ionosphere are thus thought to be secondary effects resulting from intense, but invisible, bursts of ultraviolet radiation in the portion of the sun exhibiting the "flare."

By detailed and quantitative measures of the properties of the observable "flare" radiation it is hoped that theoretical studies can be made relative to the nature and cause of the complex flare phenomenon. Certain studies of the variation with time of the $H\alpha$ flare intensity are now available. Photometric light curves have been derived for all flares recorded at the McMath-Hulbert Observatory since January, 1949. The $H\alpha$ intensities at maximum of the flares or flare-like brightenings ranges from 50 to 200 per cent of the intensity of the continuous spectrum adjacent to $H\alpha$. In general, unless $H\alpha$ intensity becomes as great as 80 per cent of the continuous spectrum, there is seldom an associated sudden "fadeout" in long-wave radio transmission. Cooperative programs with Cornell University and the National Research Council of Canada have made possible an extension of the flare study to radio wave lengths. The observational program is just approaching the point where theoretical studies can be undertaken with profit.

The second class of terrestrial effects thought to be a result of solar

causes are those phenomena associated with the term *geomagnetic storm*—and it is the geomagnetic storm that has engendered much of the current interest in solar-terrestrial relations. A geomagnetic storm is a period in which there are marked and continued variations in the three magnetic elements recorded in many different parts of the earth. Electric currents more intense than those used in commercial telegraphic and cable communications are induced in the earth's crust. There have been no observations to date to show that the sun exhibits any outstanding activity at the exact time of onset of this type of terrestrial storm. Why then is it believed that something associated with the sun is responsible for these geomagnetic disturbances? The conviction stems primarily from two facts. The first is a well-established tendency for geomagnetic storms to recur at intervals of twenty-seven days. As seen from the earth, the sun continually turns on an axis and completes one rotation in about twenty-seven days. If a solar region were responsible for a geomagnetic storm during one rotation of the sun, it would be similarly placed with respect to the earth twenty-seven days later and might reasonably be expected to repeat the disturbance. The twenty-seven-day recurrence pattern for geomagnetic storms is thus strong evidence for a solar influence in the causation of these world-wide disturbances.

The second finger pointing toward the sun as the responsible agent is the fact that geomagnetic storms often begin several days after the passage of great sunspot regions across the central meridian of the sun. This is especially the case if a great flare has occurred within the sunspot group while it was near the central part of the solar disk.

It is thought that streams of particles are ejected with high velocity from these solar storm centers. The particles move with velocities so great that they traverse the 93,000,000 miles between the sun and earth in one, two, or three days. If they encounter the earth, they so bombard its atmosphere that its electrical properties are changed and a geomagnetic storm results. These ideas may be correct, but there are many inconsistencies in the data. Not all large sunspots and flares result in terrestrial disturbances. Even more confusing is the fact that there are many geomagnetic storms when no significant spots or flares were visible on the sun. It is obvious that additional observations and new theoretical considerations are needed.

Observations of the type now being made at the McMath-Hulbert

Observatory may prove of value in efforts to identify and understand the phenomena on the sun that are associated with disturbances on the earth. On the other hand, solar-terrestrial relationships may remain illusive and poorly understood for a very long time. Man is just at the threshold of trying to solve, at the practical level, some of the problems presented by the astronomical environment of the earth. The universe is probably much too complicated to yield its secrets readily.